Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

Modeling dust composition

Carlos Pérez García-Pando

Earth Sciences Department

Barcelona Supercomputing Center

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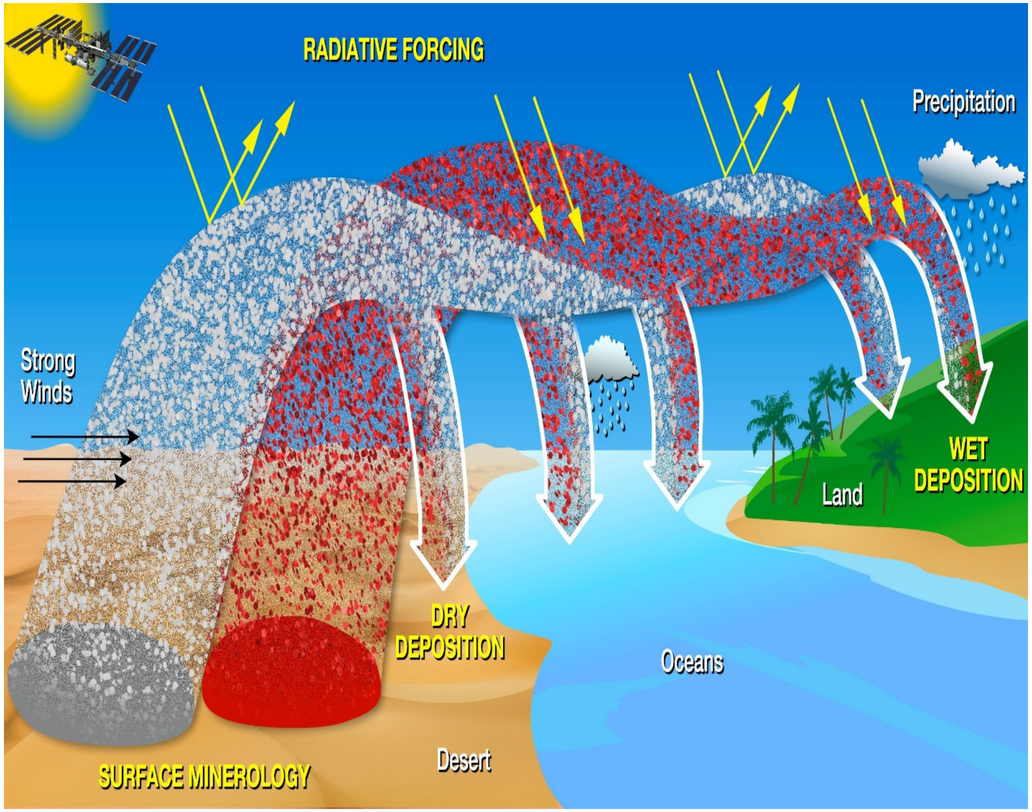
Goldschmidt, Paris

Motivation

Models typically assume **globally uniform** physical and chemical dust **properties** despite known regional variations in the mineral content of the parent soil and the emitted dust aerosols



Courtesy Robert Green (JPL)

Shortwave absorption
hematite

Longwave absorption
calcite, clays, quartz

Nucleation of ice crystals
feldspars and clays

Heterogeneous uptake
e.g. calcite

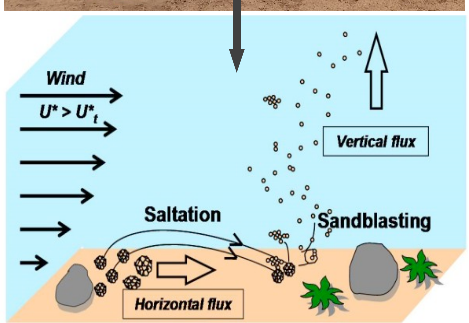
Partitioning of semi-volatile inorganic compounds
K, Ca, Mg, Na

Bioavailable iron
clays and iron oxides

This talk

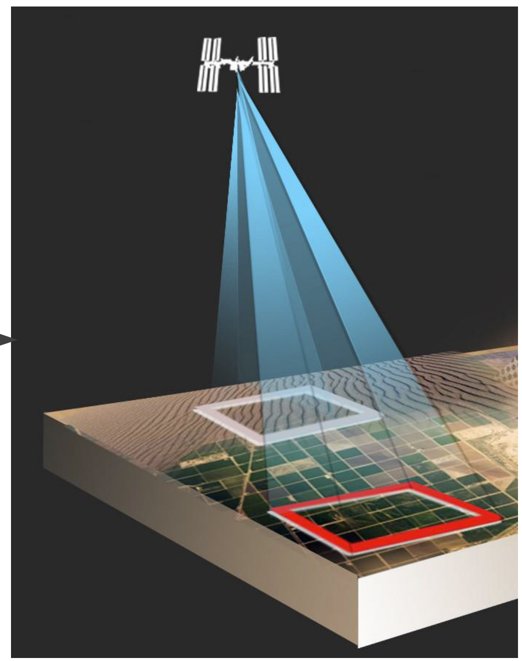
Constraining the size-resolved mineral composition

Field campaigns
Theory



Emitted dust PSD
Size-resolved minerals

Imaging spectroscopy
field-airborne-spaceborne



Improvement of soil mineralogical atlases

State-of-the art

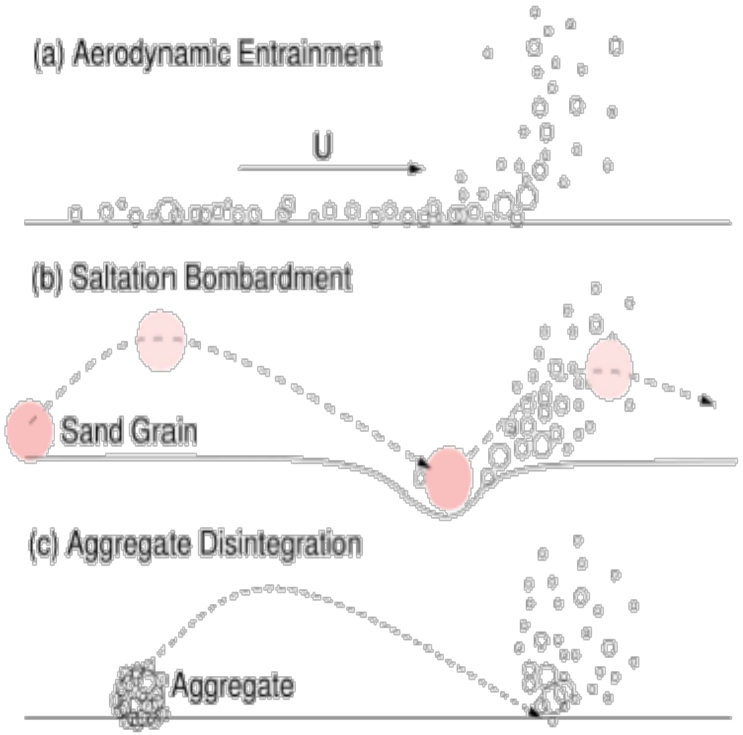
Problems

Questions

How to tackle them?

Total emitted dust PSD

Emitted PSD of dust minerals is critical to properly quantifying their climate effect

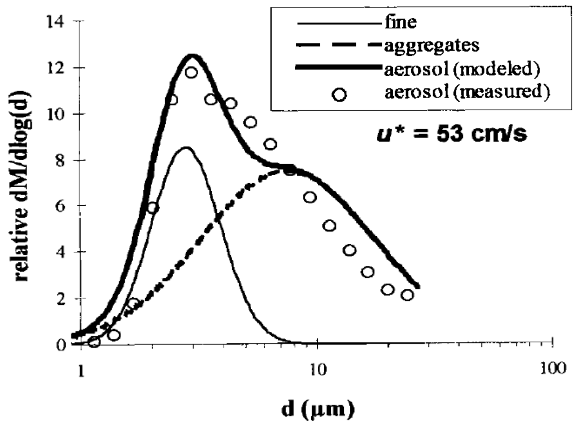


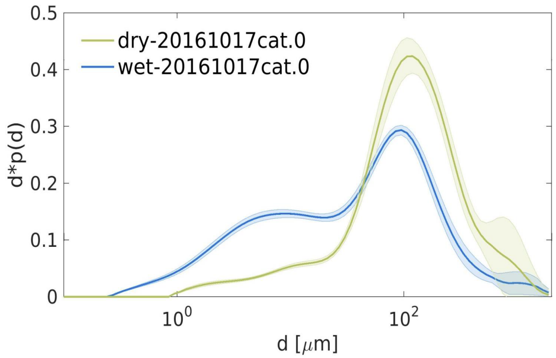
From Shao et al. 2011

Even disregarding the complexity of mineralogy

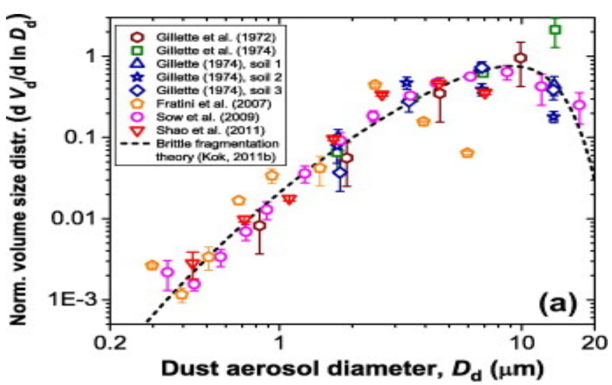
- Incomplete understanding of the physics
- Paucity and incompleteness of measurements
- Contradiction among theories, field observations and wind tunnel experiments

Total emitted dust PSD





Courtesy Martina Klose



Alfaro et al. – Dust Production Model

- Three lognormal modes
- Bonding energy of aggregates
- Kinetic energy of saltators
- PSD depend on wind (based on wind tunnel)

Shao model

- Weighted average between disturbed and undisturbed PSD
- Weighting factor ~ 2 empirical coeffs and wind
- PSD depends on wind (based on wind tunnel
- Revised version in 2011 based on measurements

Kok model (brittle fragmentation)

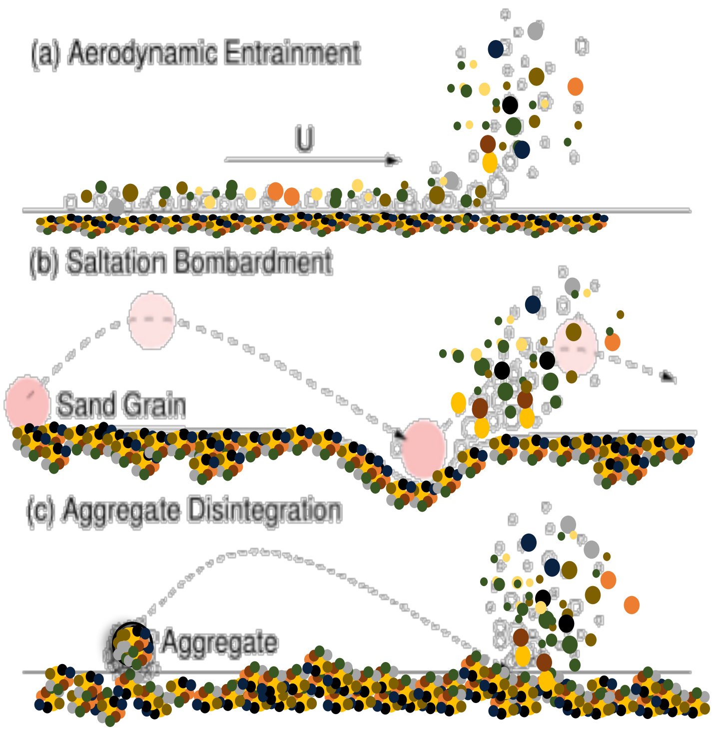
- Following the physics of brittle materials
- Emitted PSD independent of both the undisturbed soil PSD and the wind speed
- Dispersed soil PSD and the side crack propagation length (λ) assumed constant

Questions I

- Does dust PSD depend on wind speed?
- Lognormal modes, binding forces, empirical coefficients are soil-specific?
- Range of variability of λ in BFT?
- λ dependencies such as dry aggregate stability?
- How can we account for it?
- Emitted PSD and emission mechanism?

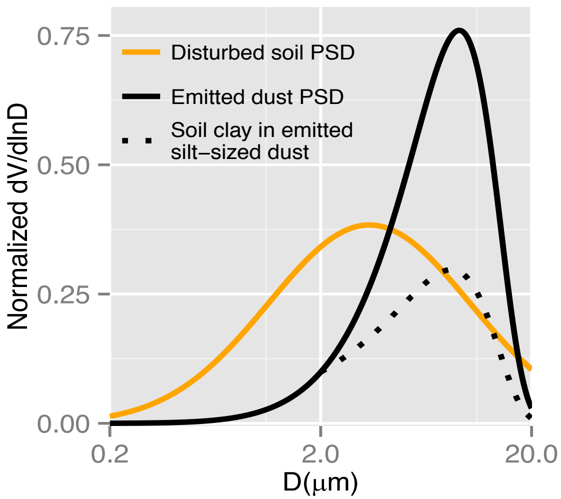
Emitted dust PSD and mineralogy

With mineralogy the picture becomes even more complex



- Complete lack of experimental studies tackling the relationship of the emitted PSD and soil mineralogy
- Mineralogy atlases are extrapolated from a limited amount of measurements based on soil type
- Measurements based upon wet sieving that disturbs the soil samples
- Internal and external mixtures of different minerals
- Iron oxides occur as both small accretions and pure crystalline forms

Recent progress in the emitted PSD of minerals



$$\frac{dV}{d\ln D} = \frac{D}{C_V} u(D) \exp\left[-\left(\frac{D}{\lambda}\right)^3\right]$$

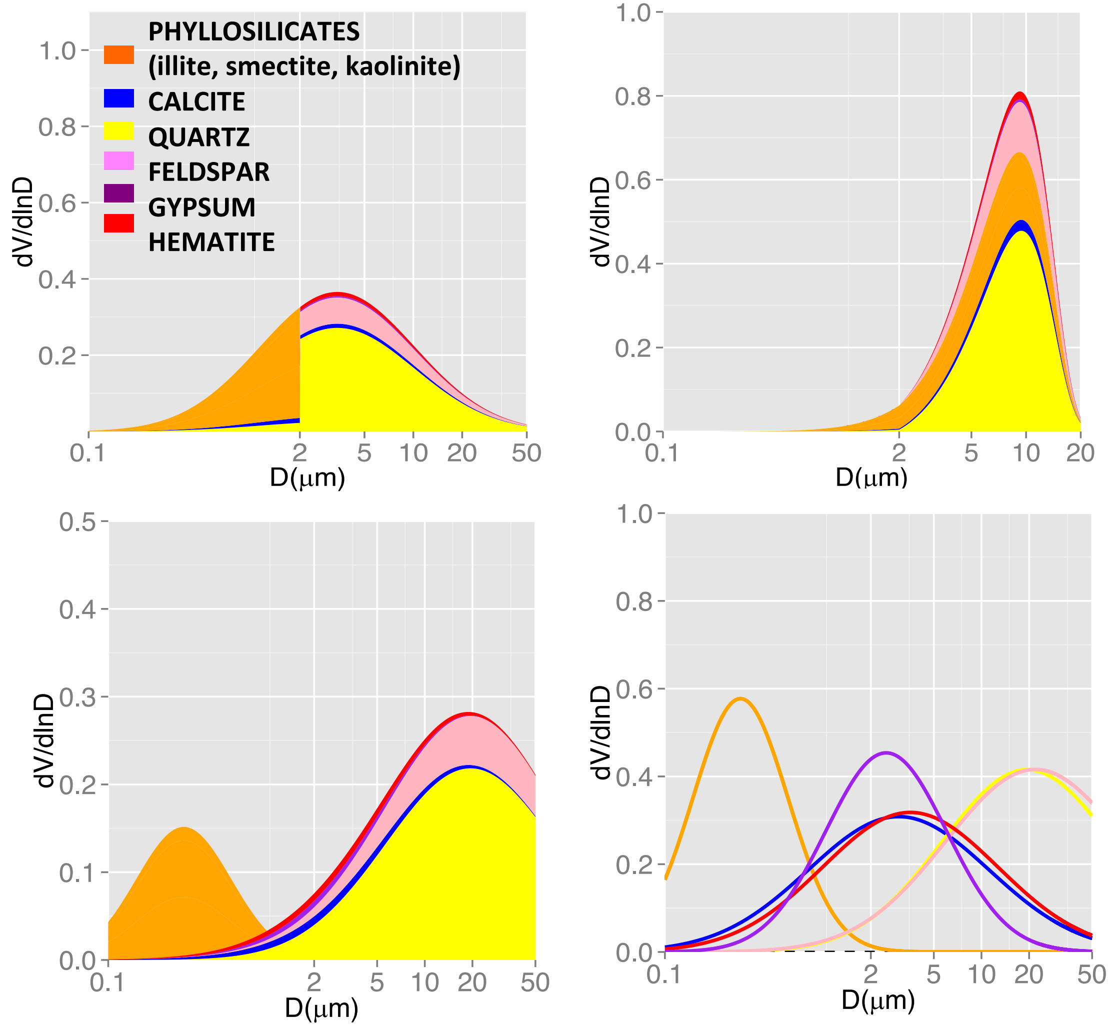
Kok 2011

BFT auspicious for mineralogy as it is based on the soil dispersed PSD

BFT extensions based on fitting Mineral- specific soil PSD´s further improve the results

Soil PSD

Emitted PSD



Perlwitz et al., 2015a,b

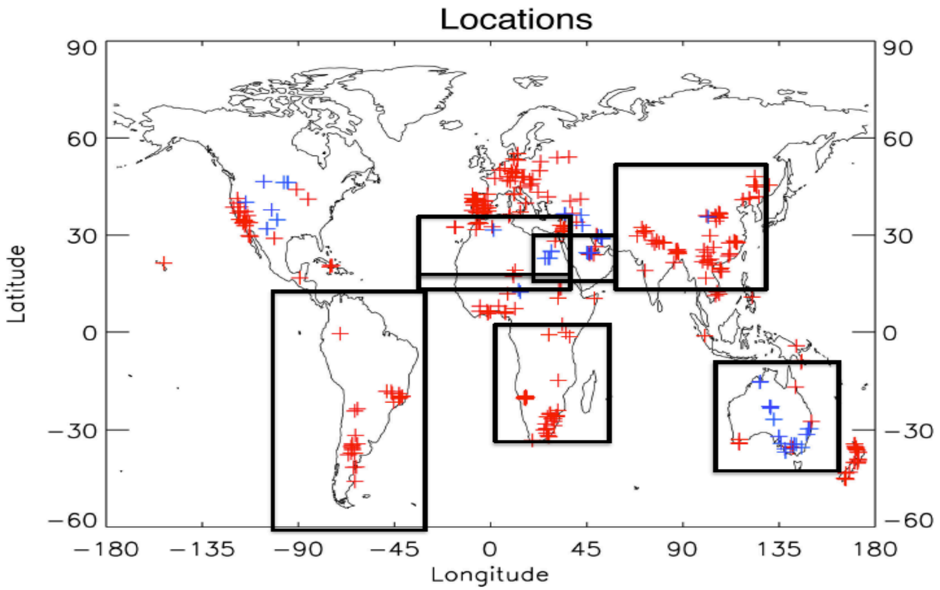
Pérez García-Pando et al., 2016

Pérez García-Pando et al., in prep

Questions II

- Observed size-resolved mineralogy of the soil and the emitted dust support BFT and extensions?
- Typical dispersed PSDs for each mineral?
- Emitted mixing state compared to the dispersed and undispersed soil?
- Best strategy to derive the mineral-specific disturbed PSDs from existing global soil texture and soil mineralogy?

Mapping of soil-surface mineralogy for dust modeling

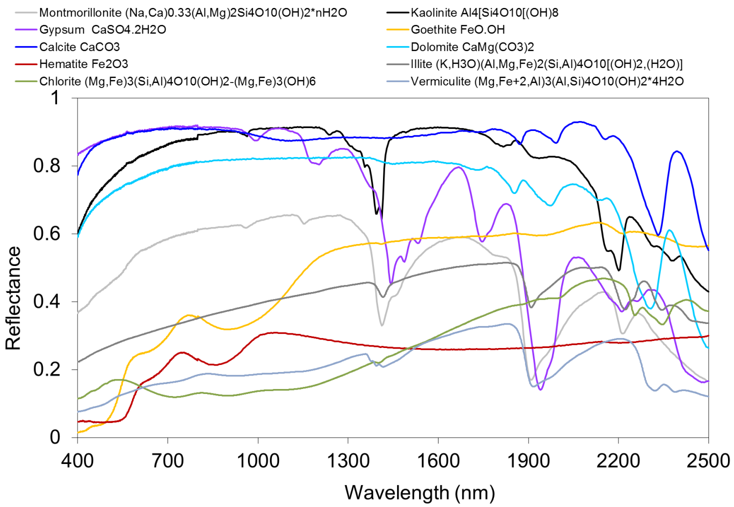


Claquin et al., 1999
Journet et al., 2014

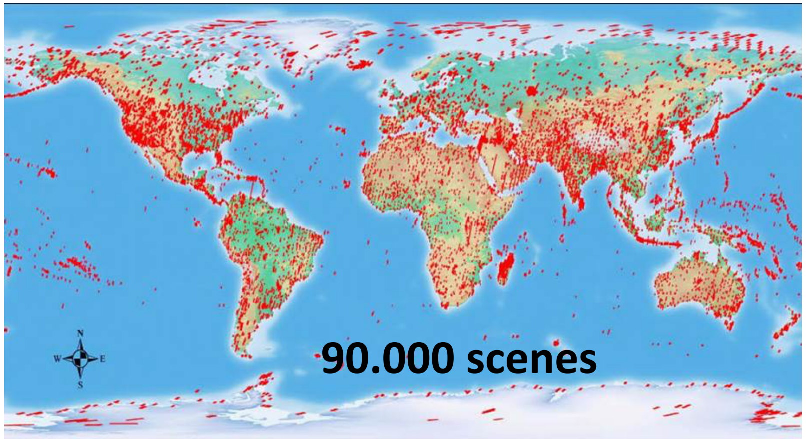
- Currently 12 key minerals estimated
- 700 soil descriptions sampling 55 % of FAO soil units
- Many regions including prolific sources not sampled
- Massive extrapolation based on soil unit/type
- A number of assumptions to overcome the lack of data: for example on hematite and goethite size

Coming space borne hyperspectral imaging spectroscopy

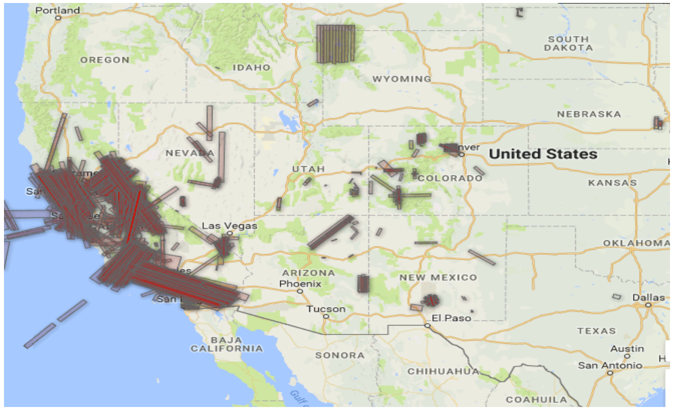
VSWIR Spectra of Dust Source Minerals



Hyperion: satellite hyperspectral sensor 0.4 to 2.5 µm, 242 spectral bands, 10nm spectral resolution, 30 m spatial with a SNR of ~50:1

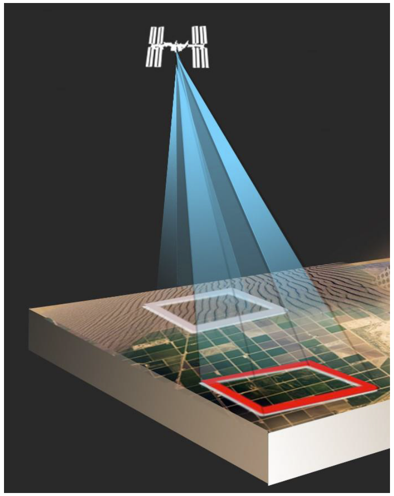


AVIRIS airborne scenes
0.4–2.5 µm, 224 bands, 10 nm spectral resolution, SNR of ~500:1



Coming soon, e.g., EnMap (~2019) Germany

EMIT (under review) NASA, US

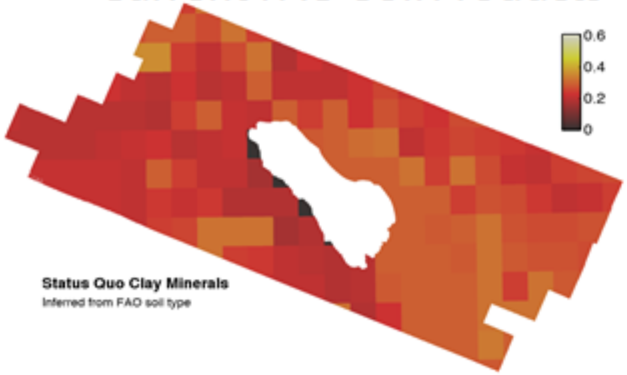


Coming space borne imaging spectroscopy may help

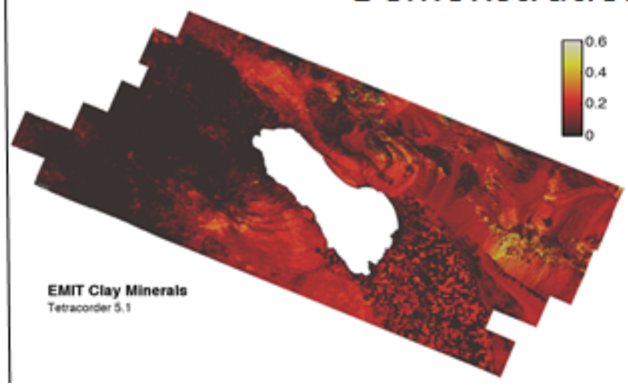
Current VSWIR hyperspectral imaging spectroscopy enables a factor of 1,000,000 improvement knowledge with respect to the current data used to constrain Earth system models for understanding and prediction.

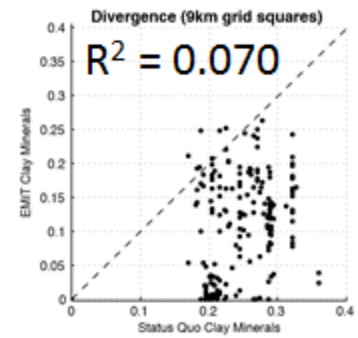
Salton sea

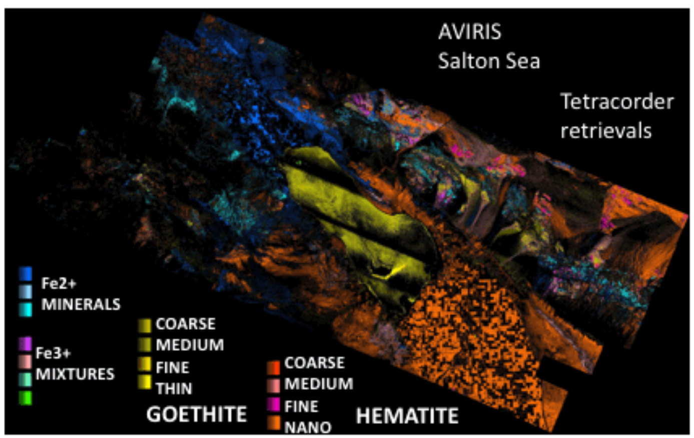
Current FAO-Soil Products



Demonstration Products







Caveat: feldspar and quartz beyond spectral Window covered by planned spaceborne missions

Courtesy Robert Green and Roger Clark

Questions III

Imaging spectroscopy for mineralogical mapping in dust modeling

- How well is the surface mineralogical composition retrieved compared to field spectroscopy and laboratory measurements of soil samples?
- How does composition vary as a function of grain size retrieved from spectroscopy?
- How do we relate mineral abundance and grain size information derived from spectroscopy to mineral abundance and PSD derived from both disturbed and undisturbed soil samples?
- How homogeneous is the composition of the soil as a function of spatial scale?
- How do we combine existing soil mineralogy atlases with information from spaceborne retrievals?
- Do theoretical and modeling frameworks need to adapt to surface spectroscopic retrievals?

How? (I)

Field campaigns

- Variety of soil types, textures and landforms
- Multiannual measurements whenever possible
- Size-resolved dust flux with optical spectrometers, multistage cascade impactors and additional passive samplers
- Saltation sediment with passive samplers and saltation sensors
- Wind and temp profiles, RH close to the ground with meteorological tower
- Soil sampling: stratified random sampling (1cm)
- Soil moisture (max 1cm) with time-domain reflectometry sensors

Laboratory analysis, theory and hypothesis testing

- **Identifying emission mechanism:** comparing the PSD of the minimally dispersed and dispersed soil and saltation sediment
- **Confronting three main PSD theories, exploring dependencies on wind speed.**

- **Explore potential dependency of λ upon aggregate stability**: mean weight diameter of the minimally dispersed soil PSD and aggregate disintegration aster various levels of sonic sieving
- **Size-resolved composition, chemistry, morphology and mixing state of soil and emitted PSD**: X-ray diffraction (XRD); scanning electron microscopy (SEM), X-ray spectroscopy (EDS), backscatter electron diffraction (BSED) -> **testing BFT and extensions**

How? (II)

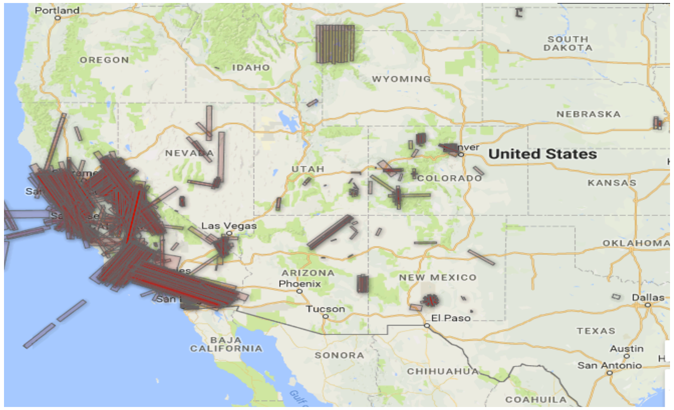
Coincident field experiments and available airborne hyperspectral spectroscopy

- Airborne and field spectroscopic measurements
- Spectroscopic measurements of soil samples
- Link/compare to XRD, TEM, SEM and BSED analyses of soil samples and emitted samples

- Comprehensive understanding of the relationship between spectroscopic retrievals and soil analysis in terms of mineral abundances, grain sizes and mixing state

- Relationship to disturbed and undisturbed soil

- Feldspar and quartz undetected -> how to combine mineral abundances and grain sizes from spectroscopy with feldspar and quartz from soil analyses?



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Thank you

Carlos Pérez García-Pando

carlos.perez@bsc.es